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Preventing Livestock Water From Freezing

Project Record
8322 1203

2200—Range

San Dimas, CA

November 1983

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COVER: *Photograph by Darol Dickinson, Dickinson Livestock Marketing, Calhan, Colo.—Ice in stock tank being broken up on a ranch in central Colorado.*

Preventing Livestock Water From Freezing

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INTRODUCTION AND SUMMARY

Many ranchers and farmers are faced with the problem of maintaining ice-free drinking water for livestock during freezing weather. The ponds and tanks used by livestock are often at remote sites where accessibility during winter often can become difficult or impossible. Even if accessible, a ranch or farm hand may need to break up surface ice on a daily basis to maintain drinking water for livestock.

At the request of the Structural Range Improvements Workgroup, VREW [1/], the San Dimas Equipment Development Center (SDEDC) investigated state-of-the-art approaches to preventing livestock water from freezing. Our survey of what is available is presented in this Project Record, which covers the following approaches:

- Water circulation
- Mass insulation
- Heat pipe
- Solar energy

No tests have been performed using any of the approaches, which are summarized in table 1. The entries in the table result from the survey and a literature search. Since there are many aspects of freezing prevention that are not available in the literature, the table *cannot* be considered complete and unexpandable.

To evaluate methods of preventing livestock water tanks from freezing, the freezing phenomenon should be understood. It is explained by Hsu and Pizey, 1981: "The cooling of a large body of fresh water can be described as convective until the body reaches a uniform temperature of 39° F (4° C), at which point the density extremum has been reached and convective circulation ceases. Further cooling with eventual ice growth occurs by unidirectional heat conduction. A vertical section through an ice-covered body of water reveals a temperature gradient varying from some temperature less than 32° F (0° C) at the top of the ice sheet, to 32° F (0° C) at the phase front to 39° F (4° C) at some location beneath the ice region called the thermocline. Below the thermocline, the water is isothermal at 39° F (4° C)." Livestock tanks cannot be classified as large bodies of water, as cooling from the edges is significant. Even when ice forms on the inside of the tank sides, there are still convective currents that tend to cool the overall mass below the 39° F (4° C) point. Nevertheless, the cooling mechanisms are basically the same as for larger bodies of water.

During freezing, water becomes supercooled to at least 28° F (−2° C). In this condition, the slightest disturbance is sufficient to make ice crystals form almost instantaneously through the supercooled layer. These quickly solidify into a solid mass on the surface, bringing the ice-water interface back to 32° F (0° C) as just described.

There are four basic sources of energy for preventing water from freezing. These are: (1) Heat from the ground, (2) heat present in the incoming or make-up water, (3) external energy sources, and (4) solar energy gain.

Heat gain from the ground is quite small. Depending on assumptions (including latitude, height of water table, etc.), it can range from 2 to 6 W/m^2.

Heat present in the incoming water may be the major contributor of heat energy to prevent freezing. If water comes from a deep well or a natural spring, it will probably come out of the ground at a temperature of 55 to 60° F (13 to 14° C), the temperature of natural caves. Therefore, preventing temperature loss in transporting this water to the livestock tank is vitally important and piping should be buried as deeply as possible. Plastic piping provides some insulation from heat loss to the ground. In addition, transport piping should be sized as small as possible, provided they are buried deep enough to prevent freezing. Most flows will be intermittent (responding to the level in the tank), and smaller piping will reduce heat loss from stagnant water.

External sources of energy and solar energy sources are discussed with respect to specific applications in the body of this Project Record.

The greatest heat loss from either a tank or an open pond is due to surface evaporation, which is enhanced by wind. Windbreaks consisting of vegetation or slotted fencing are very effective in reducing the heat loss. Cattle access to the tank should be at the south edge. Swimming-pool-type covers of ultraviolet-inhibited plastic with multiple small air chambers greatly reduce all forms of heat loss from exposed water surfaces, while allowing solar gain during daytime. Even more effective in controlling heat loss is foil-backed rigid insulation, anchored in place and floating on the surface. Rigid insulation of the closed cell type, as used

[1/] VREW = Vegetative Rehabilitation and Equipment Workshop, an organization of governmental agencies, industrial firms, and educational institutions working together to improve rangelands and further range equipment technology.

Table 1. Livestock water freeze-prevention devices discovered in survey

Approach	Device	Source	Initial cost	Advantages	Disadvantages	Comments
Circulation of unfrozen water below ice layer	Propane gas bubbler	Stockman's Nat'l. Supply Co., Inc., Pueblo, CO	Under $100.	Dependable, low-cost, efficient	New tank of propane every 3 mo.; annual cleaning & storage	Install at bottom of tank or pond
	Wind-driven propeller: the Pondmaster	Wadler Mfg., Galena, KS	$150 to $300, depending on size	Free energy source	Dependent on wind	Not recommended for stock tanks; recommended for ponds and lakes
	Photovoltaic-powered water circulation pump	William Lamb Co., No. Hollywood, CA	$25 for pump, $350 for photovoltaic panel	Free energy source	Dependent on sun; $350 for solar panel	Proposed
Mass-insulation water tanks	Culvert tanks	Rosecoe Steel & Culvert, Billings, MT	$1,700 (typ.): see table 2; accessories & installation are extra	Dependable, passive	Installation costs	Self-contained
	Concrete tanks	Dale Greenwood, Cartwright, ND	Over $1,000	Dependable—even when -30° F (-34° C) over long period, rugged, passive	Installation costs	Not commercially available; self-contained
	Steel tanks	Henry B. Davis, Petersburg, VA	$350; installation extra	Dependable, passive	Installation costs	Commercially available; self-contained
Heat pipe metallic tanks	Heat tanks	Frederick J. Sparber, Belen, NM	$40 ea. tank; accessories & installation are extra	Dependable, passive	Do-it-yourself project	U.S. patent No. 3,943,889; not commercially available
Solar photovoltaics	Water-circulation pump	William Lamb Co., No. Hollywood, CA	$25, not including accessories or panel	Free energy source	Dependent on sun; $350 for solar panel	Proposed
	Electric coil heater	Stockman's Nat'l. Supply Co., Inc. Pueblo, CO	Under $30, not including accessories	Free energy source	Dependent on sun; $15,000 for solar panel	Proposed; not practical because of cost
Solar greenhouse effect	Solar-heated, water-immersed insulated tank	Spencer B. Sitter, Santa Fe, NM	$1,000; accessories & installation extra	Free energy source, passive	Dependent on sun	U.S. patent No. 4,108,156; not commercially available
		Solar Energy Research Institute (SERI)	$600	Free energy source, passive, simple, low-cost	Dependent on sun	Proposed
	In-the-ground insulated tank	Randall L. DeGroot Columbia, MO	Not available	Free energy source, passive	Dependent on sun	Not commercially available—only proposed
Solar collector flat-plate thermosiphon	Flat-plate collector using thermosiphon	Components commercially available	$500; accessories & installation extra	Free energy source	Dependent on sun	May not be practical because flat-plate collector must be below heat exchanger
Solar collector with photovoltaics	Active flat-plate collector with electric pump and heat exchanger	Most components commercially available	$1,900 estimate; accessories & installation extra	Free energy source	Dependent on sun	Proposed system
	Active flat-plate collector with electric pump and heat exchanger in water-immersed insulated box	Most components commercially available	$2,500 estimate	Free energy source	Dependent on sun	Proposed system
	Solar pond with electric pump	Undergoing research at various institutions	Not known	Free energy source	Needs large area	Not practical at this time
Insulation covers for top and side insulation	Swimming pool type covers; side insulation	Commercially available	$200–$600	Passive	Installation and maintenance may be problems	Suggested by Solar Energy Research Institute

around the foundations of houses, would be most effective in reducing the heat loss from the sides of an above-ground tank.

A tank may be set into the ground approximately 1 ft (30.5 cm) to aid in keeping it warm and also to provide stability against wind. This must be considered in the light of the overall water requirement. For example, if a horse is in the pasture, it will break thin ice, thereby making the water available for other animals. This generally requires that the tank be low enough so that a horse can get a foot over the rim. Occasionally, a horse will rear up on its hind legs and break ice in a high tank with its front feet.

Disadvantages of setting a tank into the ground also should be considered. If the tank is filled only periodically (e.g., by a windmill), and the water level gets below ground level, neither horses nor cattle can drink. Another disadvantage of a partially submerged tank is that animals, particularly young ones, may be crowded into the tank by the rush of the herd in a hurry to drink. This is more likely to occur in summer than winter, but needs to be considered year around.

If sources of solar or external energy are provided to prevent freezing in winter, these sources should probably be removed in summer to prevent overheating and evaporation of the water.

WATER CIRCULATION

There are two commercially available freeze-preventative devices that circulate standing water to take advantage of the fact that when there is surface ice on stock water supplies there is denser, warmer liquid water below the ice layer. Circulating this denser, warmer water thaws a portion of the frozen surface; this enables livestock to obtain drinking water. Circulation actually increases heat losses from the tank, as the 39° F (4° C) water rises to the surface where it may be further cooled by wind and evaporation. These losses may not be sustainable from the tank's heat reservoir that is derived from the earth, incoming water, and solar gain. The commercially available freeze-preventative products utilizing this principle are a propane gas bubbler and a submerged propeller—an agitator that is wind-driven. Also proposed is a photovoltaic (solar panel)-powered water-circulation pump.

Propane Gas Bubbler

A propane gas bubbler, marketed by Stockman's National Supply Co., Inc., P. O. Box 917, Pueblo, CO 81002 (telephone: 800/525-5393), slowly releases bubbles from

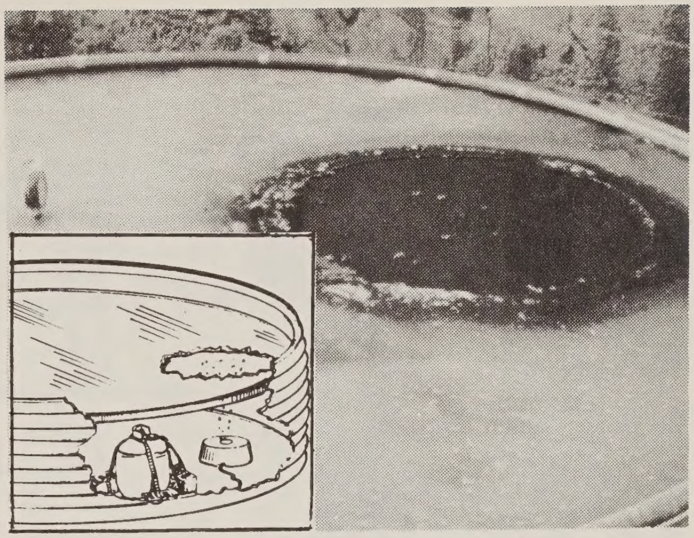

Figure 1. Propane gas bubbler installed in stock tank.

a 5-gal (19-liter) tank of propane placed at the bottom of a stock pond or tank (fig. 1). The propane tank is ballasted by approximately 75 lb (34 kg) of rocks or other material. Reports from the Arizona and New Mexico area indicate that this bubbler works very well; it is dependable and maintenance free. The area of applicability of the propane bubblers and their effectiveness in maintaining an open area could be extended by insulating the stock tanks and using covers to prevent heat loss from evaporation. The system is inexpensive to install, and one 5-gal (19-liter) tank of propane lasts approximately 3 mo.

Rising propane gas bubbles circulate the lower, warmer water to the surface. This maintains an ice-free area that is approximately 1½- to 3-ft (½- to 1-m) in diameter, depending on the depth of the bubbler and the air temperature. The deeper the bubbler, the larger the opening in the ice surface. Propane is nontoxic to livestock and humans, and cannot ignite at the low-concentration level dispersed by the bubbler.

The bubbler and propane tank should be removed from the water supply each spring for cleaning and storage. Late in the fall, the propane tank should be refilled and, along with the bubbler, reinstalled under the water. The bubbler costs less than $100, not including the propane tank. Propane costs approximately $1/gal ($0.26/liter).

Wind-Driven, Vertical Axis, Below-Surface Propeller

Wadler Manufacturing Co., Inc., Rt. 2, Box 76, Galena, KS 66739 (telephone: 316/783-1355), produces a device that utilizes a Savonius vertical rotor, or windmill, to provide an ice-free area on stock ponds. This device—the Pondmaster—consists of a vertical two- or three-bladed Savonius rotor that is directly connected to a vertical

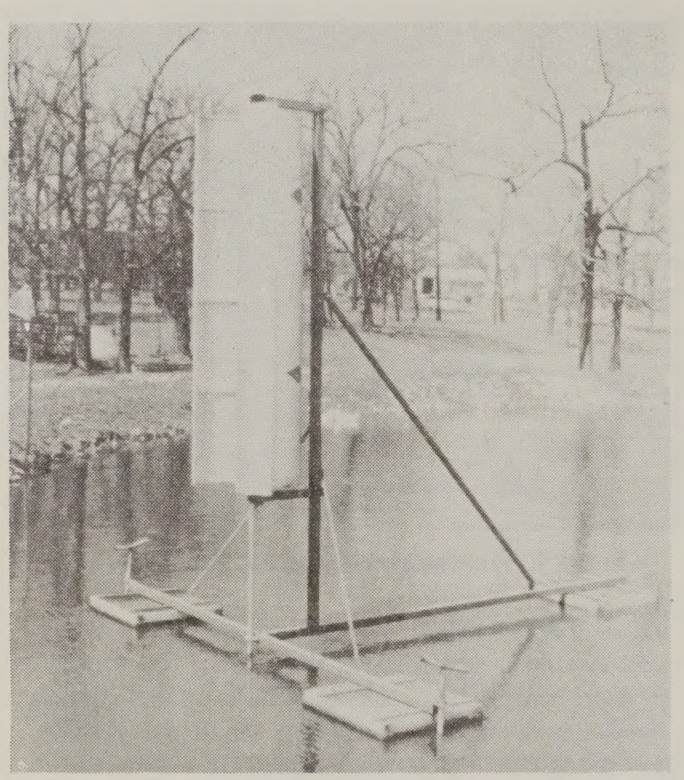

Figure 2. Wind-driven, vertical-axis, below-surface propeller installed in stock pond.

driveshaft, which turns a submerged propeller or agitator. The model 672 Pondmaster mounted on a model 1078 float assembly is seen in figure 2. Here, the propeller (instead of gas bubbles) is used to circulate warmer water to the pond surface to maintain an ice-free area.

The manufacturer reports that, while these wind-driven propellers—costing from $150 to $300, depending on size—work well in ponds and lakes, they are not specifically recommended for use in stock water tanks. This is because a large supply of warmer water, as found in a large pond, makes the devices work better. However, while they are not specifically recommended by the manufacturer for stock tanks, the Walder firm reports that they do work in tanks and have been so used. Further, if the stock tank is insulated and partially covered, the firm states the effectiveness of the Pondmaster is improved.

While the Savonius rotor is not an efficient type of wind machine, it is well suited for this application because of its simple construction and ability to be rotated by a wind from any direction without having to turn into the wind. The device has a low installation cost and uses a free source of energy. It is most dependable in flat, unsheltered areas where there are prevailing winds.

In the event there is no wind, which (unfortunately) occurs quite often during the coldest weather, the ice-free area freezes over. However, the Pondmaster's driveshaft is protected at the water surface by a specially designed sleeve. When the wind again comes up, the rotor turns, again thawing a patch of surface ice.

A second problem is that the circulation of water may promote excessive cooling of the tank by bringing water at 39° F (4° C) from the bottom to the surface where high winds will cause increased evaporation and cooling. This may, in some circumstances, result in heavier ice formation than without the wind turbine stirring.

If the inlet to the tank were a spring or pipe bringing in water at 55° F (13° C), the temperature of natural caves, it may be more advantageous to anchor the wind machine directly over this warm water source. This approach would be the most effective if most of the tank were to freeze over with no wind and only a small area above the inlet were to be unfrozen when the wind started. The warmest water would then be brought only to the small open surface. Of course, covering most of the pond with floating insulation would also aid in preventing the stock water tank from freezing over.

Photovoltaic-Powered, Water-Circulation Pump (Proposed)
By powering a small pump using a photovoltaic panel, water circulation can be established. (For more information, see section on Photovoltaics.)

MASS INSULATION

Another method of providing ice-free drinking water for livestock is to insulate the water supply in an enclosed tank with only a small outlet, or trough, permitting access to the water by livestock. This approach is based on the principle of exposing only a small portion of the water supply to freezing temperatures and retaining the majority of the water in an enclosed tank, using the make-up water and the ground both as a heat source and insulator.

The basic design for mass-insulated, frost-free tanks is seen in figure 3. Water for the livestock is provided in a trough that is connected to the water supply beneath the water surface. Air is trapped in the tank, and colder ambient air is prevented from entering. Warm water recharges the tank from a pressure line; the level is regulated by a float valve.

In general, mass-insulated tanks perform well. They are probably one of the simplest and most direct approach for preventing stock water tanks from freezing. These insulated tanks are maintenance free and function independently of weather conditions. A system of

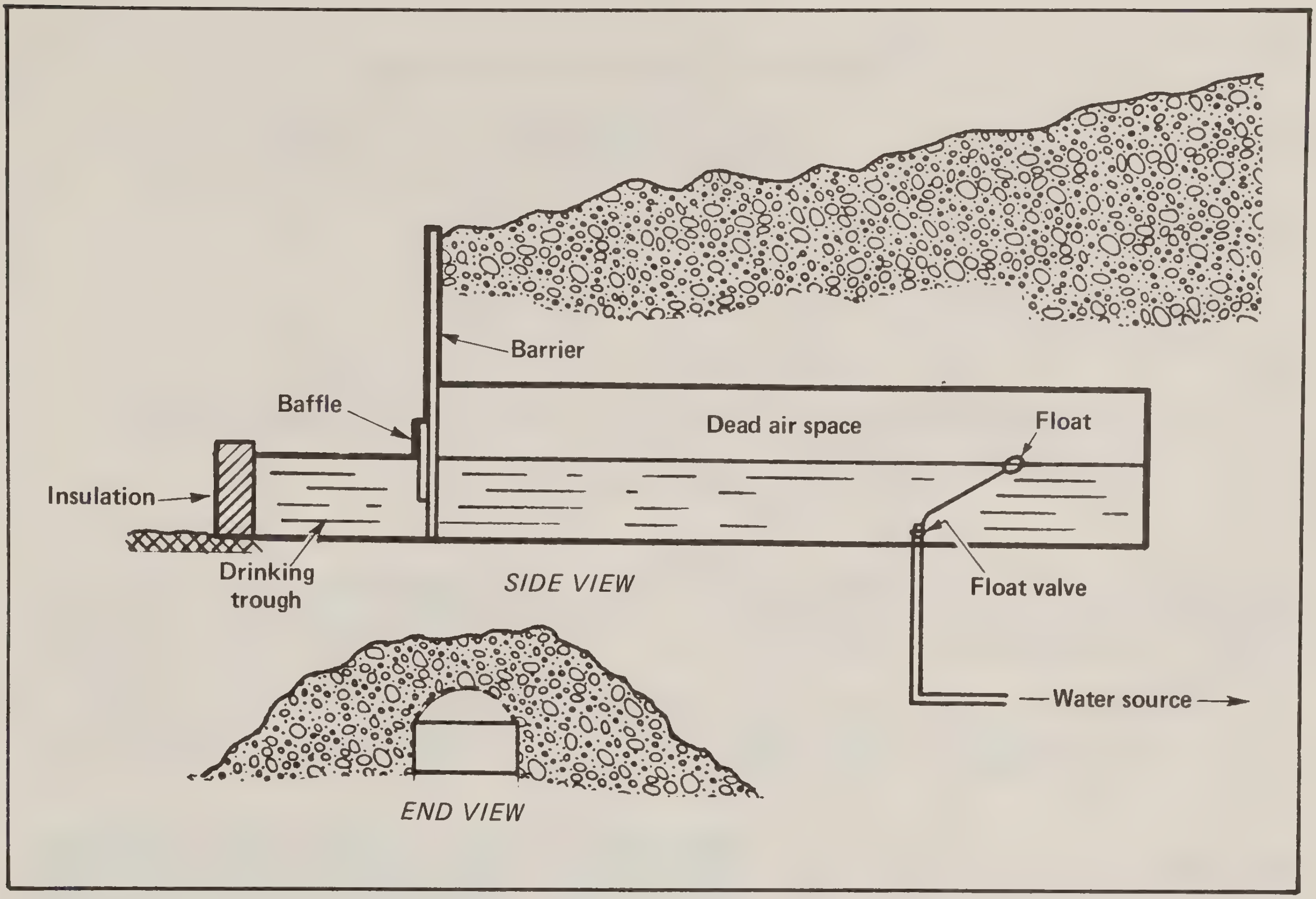

Figure 3. Mass-insulated, frost-free tank schematic.

the frost-free tanks can disperse livestock animals so they do not have to crowd around a single water supply. However, high fabrication and installation costs present a problem. The fabrication cost varies with the type of material used and the number of units produced. Commercially available tanks, unfortunately, are as expensive as units that are fabricated on site. The installation cost varies with the type, size, and weight of the tanks. These costs include excavating an area for the tank and installing a water line to each tank.

Culvert Tanks

Roscoe Steel and Culvert, Billings, Mont., manufactures frost-free tanks from 16-gage (0.064 in; 0.16 cm), galvanized,

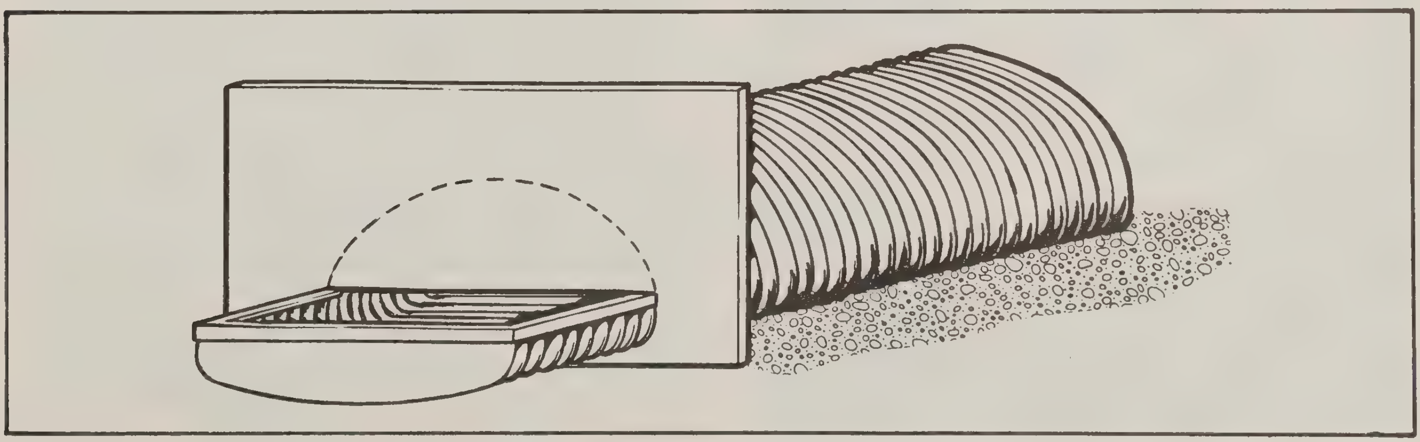

Figure 4. Mass-insulated culvert tank configuration.

Table 2. Available mass-insulated culvert steel tanks.

Arch size (in)	Arch size (cm)	Tank capacity (gal/ft)	Tank capacity (1/m)	Tank shell cost ($/ft)	Tank shell cost ($/m)	Costs of ends, drinking tub, baffle, and fittings ($)
50 x 31	127 x 79	57	708	44	144	615
58 x 36	147 x 91	65	807	51	167	788
65 x 40	165 x 102	74	919	59	194	994
72 x 44	183 x 112	81	1005	66	217	1,166
84 x 56	213 x 142	99	1129	79	259	1,374

From table 2, an 18-ft (5.5-m), 58- by 36-in (147- by 91-cm) culvert steel tank would cost: (18 ft) ($51/ft) + ($788) = $1,706.

corregated steel (fig. 4). These tanks are offered in five different arch sizes (table 2)—the purchaser must specify the length. These tanks tend to be flimsy, but work well in principle.

The initial cost does not include a float valve, the post barrier needed to stabilize the hillside behind the drinking area, or installation costs.

Concrete Tank

A Forest Service permittee, Dale Greenwood of Cartwright, N. Dak., uses reinforced concrete to construct frost-free tanks (fig. 5), thus overcoming the structural weaknesses inherent in some designs when tanks are fabricated from fiberglass or steel. The concrete tanks are 16-ft (5-m) long and 5-ft (1½-m) wide at the base; 10-ft (3-m) wide at the top. A baffle of ¾-in (1.9-cm) painted, marine plywood is bolted to the head wall.

Figure 5. Reinforced-concrete, ice-free tank installation.

These reinforced concrete tanks have a minimum estimated life of 50 yr. Approximately 20 of these ice-free tanks are used by permittees on National Grasslands to water 50 to 250 head of stock at temperatures down to –30° F (–34° C) during long periods of no sunshine. These concrete tanks work well, but have the drawbacks of being very heavy (and, thus, hard to move) and having a high fabrication startup cost.

The tank weighs 8,000 lb (3600 kg), not including the two-piece cover and head wall, and is cast upside down. The casting form cost Greenwood over $5,000 to make from 3/16-in (4.8-mm) metal plate plus metal bar ribbing and rebar steel. Other costs include $825 per finished tank and $250 for installation.

Steel Tank

Henry B. Davis of Petersburg, Va., markets a unique-type, ice-free steel tank. It is buried in the ground and the excavated fill material is placed over the tank in a crib for added insulation (fig. 6). The drinking trough is located at the top of the tank where water heated by convection is available to the livestock.

The Pecos Ranger District, Santa Fe National Forest, N. Mex., uses these tanks and reports that ice accumulation usually does not exceed 1 in (2.5 cm), except when the temperature dips below –20° F (–29° C). At first, horned cattle had trouble obtaining water due to the narrow drinking trough (fig. 7), but they eventually learned how. Another minor problem is that the water line coupling is so high, the line freezes if an inadequate crib is built. In general, the District is satisfied with these tanks, which cost approximately $350 plus freight and installation cost.

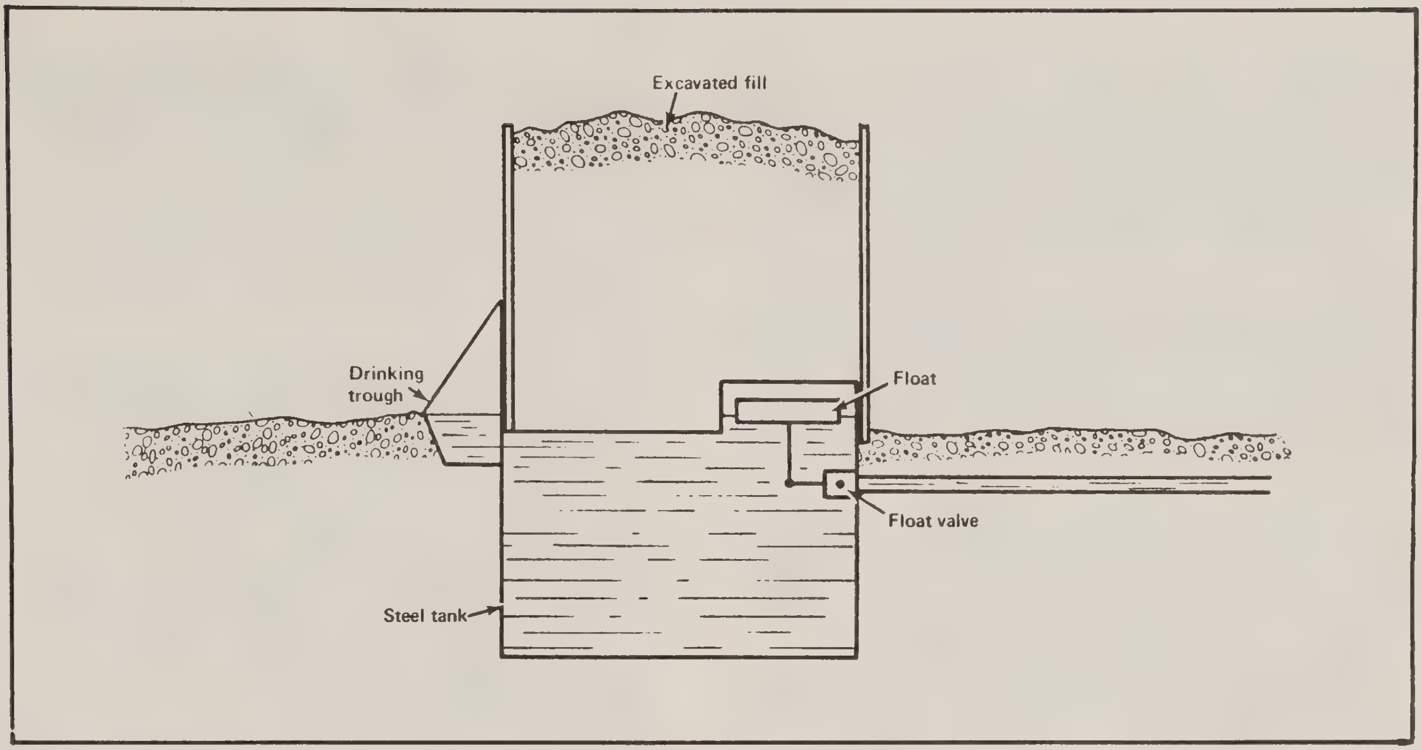

Figure 6. Buried ice-free steel tank schematic.

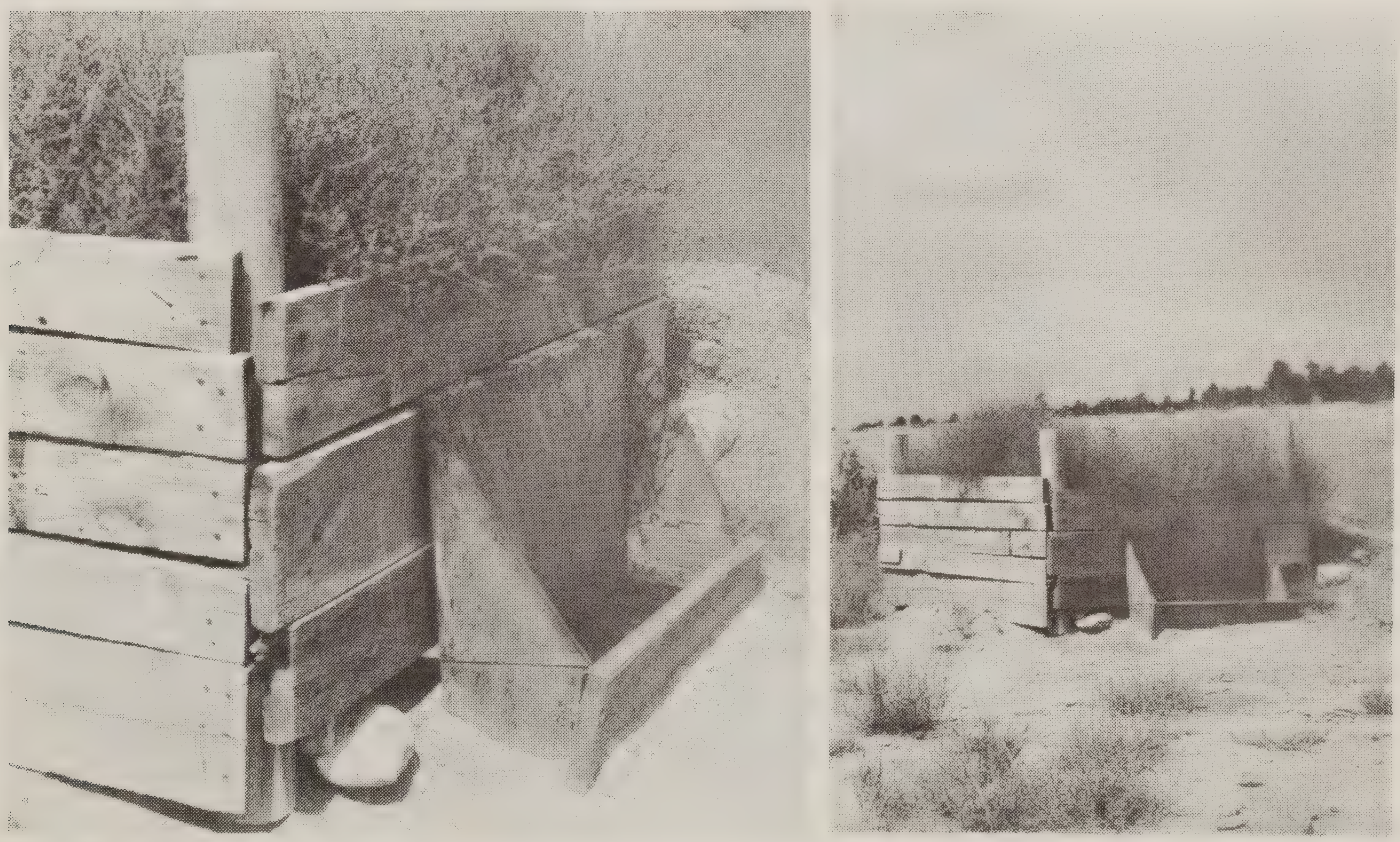

Figure 7. Ice-free steel tank installation.

HEAT PIPE

A heat pipe is an efficient heat-transfer device used when high heat-transfer rates are needed or precise temperature control for a process or device is desired. It consists of a sealed container that is evacuated and partially filled with a liquid refrigerant. The pipe transfers heat via a process of closed-cycle evaporation and condensation. When heat is applied to one section of the pipe, the refrigerant begins to evaporate; the vapor flows to the unheated section of the pipe and condenses. This releases the refrigerant's latent heat of condensation, which is relatively high, and results in a significant transfer of heat with only a minimum amount of refrigerant.

The condensate can be returned to the evaporation side of the pipe by the capillary action of a wick-like structure, or the heat pipe can be oriented vertically so that gravity returns it to the evaporator section at the bottom of the pipe. Depending on the temperature range to be encountered, various Freon formulations, ammonia, carbon dioxide, or propane can be used as the refrigerant. Heat pipes have been used for such applications as Alaskan pipeline permafrost control, waste heat recovery systems, and nuclear reactor and space vehicle temperature control.

Metallic Tanks

A heat pipe can transfer heat from both the warmer, lower portion of stock tank water and the ground beneath the stock tank to the frozen surface. Frederick J. Sparber of Belan, N. Mex., in U.S. patent No. 3,943,889 (March 16, 1976) describes "heat distributing tanks for retarding surface freezing." He uses metallic tanks as heat pipes that float at the surface of the water in a stock tank (fig. 8). They maintain an unfrozen opening around their periphery; livestock need only to push down on a heat tank to gain access to drinking water. The tanks are in use in Belen, N. Mex.

A single heat tank is generally sufficient for stock water tanks up to 6-ft (1.8-m) in diameter. Several heat tanks can be placed in stock tanks that range from 10- to 40-ft (3.1- to 12.2-m) in diameter. The heat tanks are chained down (fig. 8) to keep them near the edge of the stock water tank so they can be reached by livestock. Ballast material—lead shot or 3/8-in (9.5-mm) pea gravel—should be placed in all the heat tanks, except the one attached to the fill valve handle, so that they float just at the stock tank surface.

Heat Tank Designs and Costs

As presented in the patent, the water level in the stock tank can be controlled by attaching an unballasted heat tank to the fill valve handle (fig. 8). This particular heat tank serves as a freeze-proof float for the water inlet valve to assure that the fill valve won't freeze in the open position.

Three additional ideas (*not* seen in fig. 8) are presented in the patent. First, thermal insulation collars can be placed about the top portion of the heat tanks to concentrate the flow of

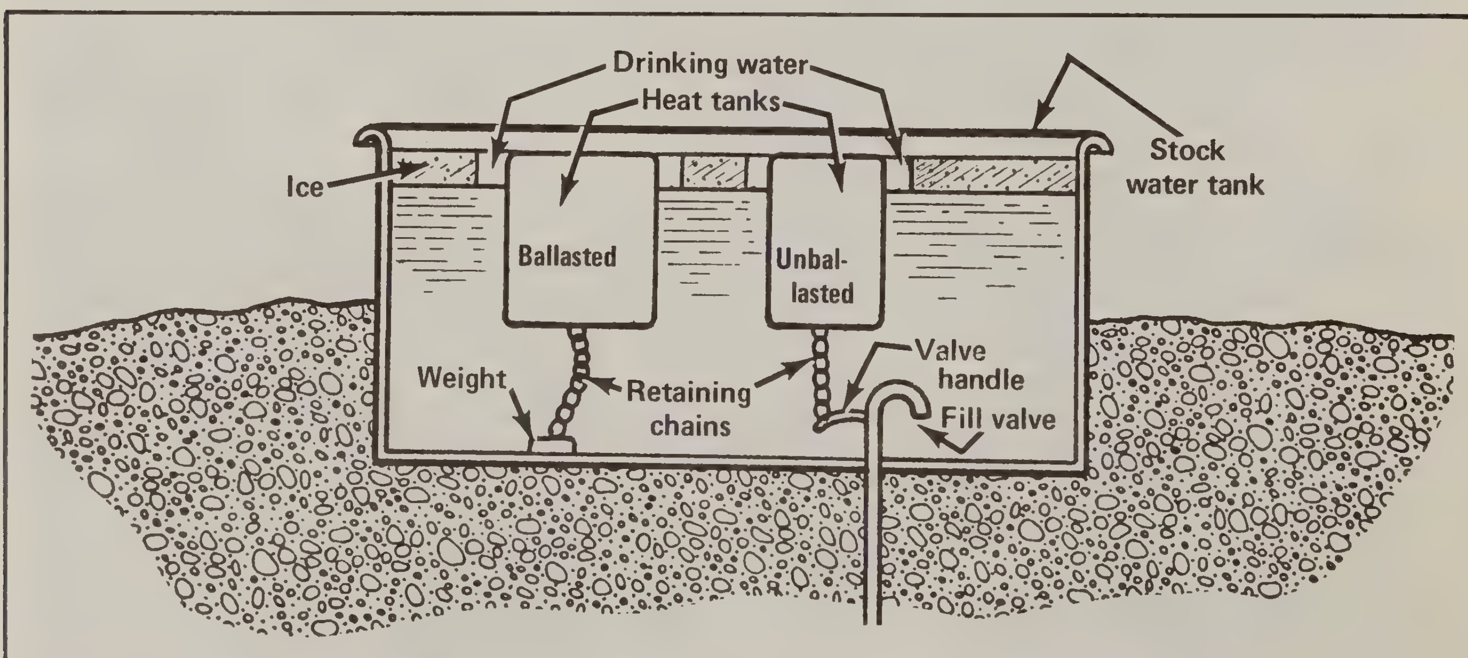

Figure 8. Schematic of heat tanks installed in stock tank.

heat to the ice that is in the immediate area of the heat tanks. The collars are suggested for use when extremely low temperatures might cause extra-thick ice to form.

Second, to reduce heat losses at the stock tank surface, thermal insulation material (e.g., styrofoam between thin metallic sheets) can be floated on the water surface. Holes have to be cut in the floating insulation cover to accommodate the heat tanks and allow stock access to drinking water. Finally, the patent presents an alternative to the use of internal ballast materials. Rings having arms can be placed around the heat tanks and the arms attached to the wall of the stock water tank to hold the heat tank in place.

While the heat tanks, which should have a surface area large enough for sufficient heat transfer to maintain an ice-free ring, can be fabricated from aluminum or stainless steel, galvanized steel is recommended because it is less expensive than stainless steel and aluminum tends to corrode. During the summer, the heat tanks—if placed in direct sunlight outside the stock water tank—might experience temperature of 140° F (60° C) and pressures to 135 psia (932 kPa). Mr. Sparber's heat tanks, which are approximately 0.7 cu ft (21 liters) in size, are pressure rated at 900 psia (8010 kPa) and can be equipped with either a blowout plug or a safety valve.

The heat tanks are fabricated by placing ballast in the tanks, then evacuating them to 100 microns of mercury (13.3 Pa), and finally backfilling them with 1 to 2 lb (0.45 to 0.90 kg) of refrigerant. The refrigerant used in the heat tanks should be capable of transferring heat at temperatures near freezing, have a boiling point below 32° F (0° C), and a critical temperature well above this. Sparber recommends Freon 114 ($C_2Cl_2F_4$) as the refrigerant for stock water tank applications since it meets these criteria. Also, it is a nonflammable, nontoxic liquid having both a low solubility in water and a relatively low vapor pressure of 0.5 to 1 atmosphere (51 to 101 kPa) at near-freezing temperatures.

Depending on quantities purchased, Freon 114 costs $2 to $10/lb ($4 to $22/kg). According to Sparber, his heat tanks can be fabricated for approximately $40 each and, for a nominal fee, he will supply construction plans and installation information for them.

The heat pipe is essentially an alternative to the propane bubbler that does not require a non-renewable energy source. It presents similar capabilities and disadvantages, but the area of applicability may possibly be extended by using some of the methods of tank insulation discussed. In colder climates than Belen, N. Mex., it is possible that the rate of heat transfer, with the limited area of the heat pipe and only a difference of 7° F (4° C) driving temperature with possibly a limited volume of 39° F (4° C) water, may not be sufficient to prevent freezing. However, the technique shows promise, appears economical, and is considered worthy of further evaluation.

SOLAR ENERGY

Solar radiation is a free source of energy that can be utilized by freeze-preventative devices for stock tanks. Large amounts of solar radiation reach the surface of the earth, varying with the location and season of the year. Figure 9 shows the average daily availabilities of the total solar radiation

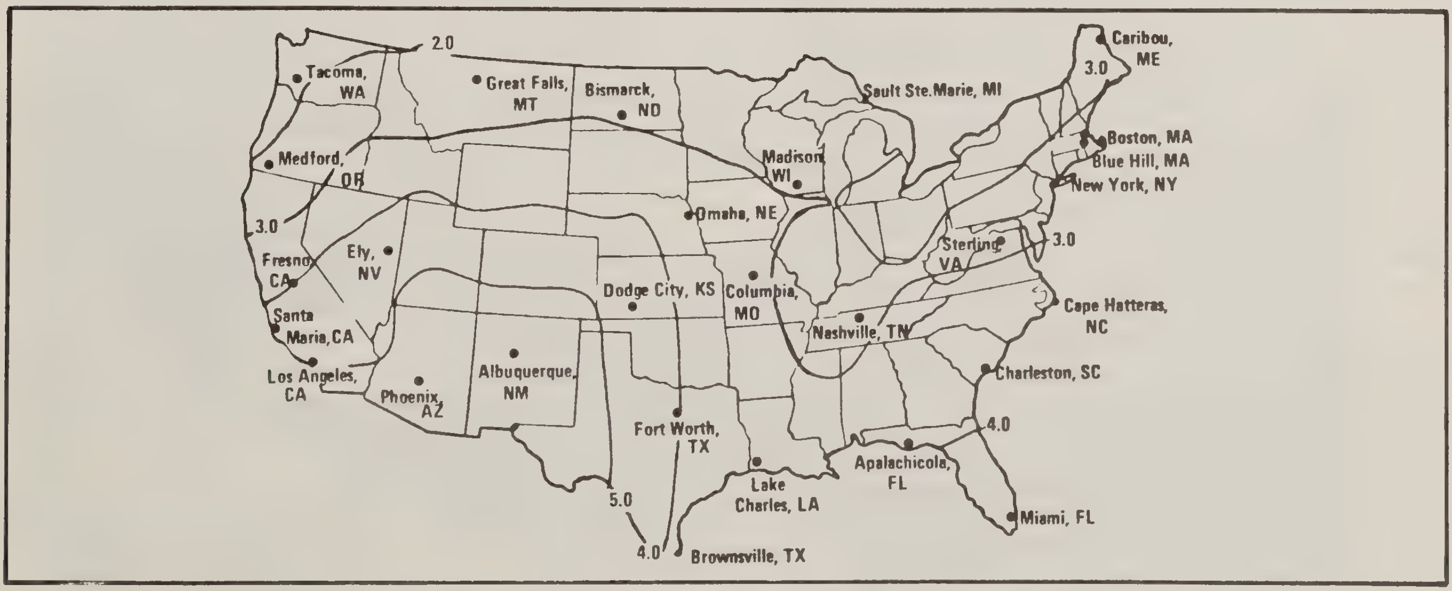

Figure 9. Bands of available solar radiation during the winter.

(kWh/m^2) on a south-facing, 45-degree tilted surface for the United States in winter. The areas receiving the most amount of solar energy and, therefore, best suited for solar energy utilization, are Arizona, New Mexico, and west Texas. In addition, enough energy to solve materially the freezing problem can also be obtained in Idaho, Wyoming, and South Dakota.

There are two approaches to harnessing solar energy; either one can be used for stock water tank freeze-preventative devices. In the helioelectric approach, photovoltaic conversion to electric energy occurs in a layer of material when solar radiation falls upon it, thus creating an electric current. In the heliothermal approach, solar radiation is absorbed, stored, and transported by media as heat.

Helioelectric

Photovoltaic solar energy conversion systems are based on the photovoltaic effect. That is, a voltage is generated when light falls on suitable semiconductor materials (e.g., selenium, copper/copper oxide, and thallium sulfide). Today, silicon crystals are widely used in photovoltaic cells. Large-scale development of these cells began with the space program and has greatly accelerated with the introduction of non-space applications in 1973. Cells for space applications had cost approximately $2,000 per watt; those for nonspace applications, primarily in remote locations where conventional electricity is unavailable, were only approximately $50 per watt in 1973. The current (1982) price of photovoltaic cells is $9 to $10 per peak watt.

Photovoltaics

Photovoltaic cell arrays mounted on panels can be located at remote stock tank sites to supply electricity to freeze-prevention devices, eliminating the need for expensive transmission lines. These photovoltaic arrays should be situated to receive maximum sunlight as well as protection from damage by livestock. A single panel can be mounted on a pole above the reach of the animals or mounted on a convenient structure, such as a windmill tower. A number of panels can be mounted on the roof of a nearby structure, or within a fenced area near the stock tank.

Some commercially available panels, costing $350 to $500 each, deliver almost 35 watts at approximately 16 volts and 2.2 amperes. The panels vary in size from 3 to 5 sq ft (0.3 to 0.5 m^2). They are typically framed with aluminum; tempered glass protects the cells from rain, hail, and snow. Solar panels currently cost $9 to $10 per peak watt of output under good conditions in sunbelt locations. Costs of under $3 per watt are projected by 1986 (Department of Energy source), as new cell fabrication techniques and increased cell production capacity come into use.

A solar array of photovoltaic cells will normally be rated at the peak output at noon on a clear day when the insulation is assumed to be 1,000 W/m^2. If an array is mounted facing south (in northern latitudes) at the latitude angle plus 17°, it will perform best during the winter months. The sun is severely attenuated early in the morning and late at night when the rays are passing through the atmosphere close to the earth's surface so that the "period of effective solar radiation" in the winter is from 1 hour after sunrise to 1 hour before sunset. During this period of "effective solar radiation," the output of the array is approximately sinusoidal peaking at noon. The total output of the array is then the integral of a half sine wave or $2/\pi = 0.636$ times the peak output times the "period of effective solar radiation." This gives the output in watt hours.

Electrical-storage components (batteries, voltage regulators, and blocking diodes) can be used in conjunction with the panels to provide around-the-clock power. However, these components add to the cost, and batteries for freeze-preventative devices are not recommended.

Water-Circulation Pump. It is important, in choosing a pump to operate with a solar array, to match the pump and array characteristics. The pump, motor, and array should be chosen so that the motor under load is rated at the same current and voltage as the maximum power point current and voltage of the solar array. Both current and voltage of a solar array vary with temperature and solar intensity. If the pump is to be used to prevent freezing, the array voltage and current should be capable of providing the necessary power at the expected winter temperature.

William Lamb Company, North Hollywood, Calif., offers a 3-gpm (0.2-1/sec) at 7-ft (2-m) head, submersible, 9-oz (0.3-kg), direct-current (12V, 2 amp), water-circulation pump for $25 (February 1982) that is wired for attachment to a photovoltaic panel. This pump, with a 1/8-in (3.2-mm) wire screen placed to prevent debris from clogging it, could be mounted on the bottom of the stock water tank with its discharge directed towards the tank surface. Whenever sunlight strikes the solar panel powering the pump, the pump circulates the water below the ice layer.

Electric Coil Heater. A costly (and thus not-too-practical) approach to providing ice-free water in the winter is the use of electric heaters that float in the stock tank and have a heating element that extends below the water surface. Two watertight, rustproof models (a 1,000 and 1,500 W) are

available from Stockman's National Supply Co., Inc., Pueblo, Colo., at $26 and $29 (October 1981), respectively. Both are equipped with a thermostat that energizes the heater only when the temperature falls below 38° F (3.3° C). These heaters can maintain a 2- to 3-ft (0.6- to 0.9-m) opening in ice, even when temperatures are far below freezing. However, to power the floating coil heater with solar cells, almost $15,000 worth of panels would be needed and they would require a large installation area. However, electric coil heaters may have advantages in locations where commercial electric power is available.

Heliothermal

Solar thermal energy can be obtained through the greenhouse effect or through the use of focusing or flat-plate collectors. The greenhouse effect is the selective admission of shortwave radiation—usually through some type of glazing that is impenetrable to longwave radiation—onto an absorption surface. The admitted shortwave radiation is partially absorbed and partially re-radiated by the absorption surface as lower energy longwave radiation. The re-radiated longwave radiation cannot escape through the glazing; it is trapped and then converted to heat, accumulating as heat energy.

Greenhouse Approaches

Water-Immersed Insulated Tank. A solar-heated, square-shaped, water-immersed, insulated water tank—designed to provide water to an attached drinking trough when temperatures are below freezing—is described by Spencer B. Sitter of Santa Fe, N. Mex., in U.S. patent No. 4,108,156 (August 22, 1978). To maximize the efficiency and protect the solar-heated tank, it should be placed facing south (in the northern hemisphere) within the southern portion of a standard stock water tank (fig. 10). The site pictured is near Datil, N. Mex.

The water supply line, which may extend upward from the ground below the standard stock tank, can serve both the solar-heated, water-immersed tank and the standard stock tank if the float valve is placed in the solar-heated, water-

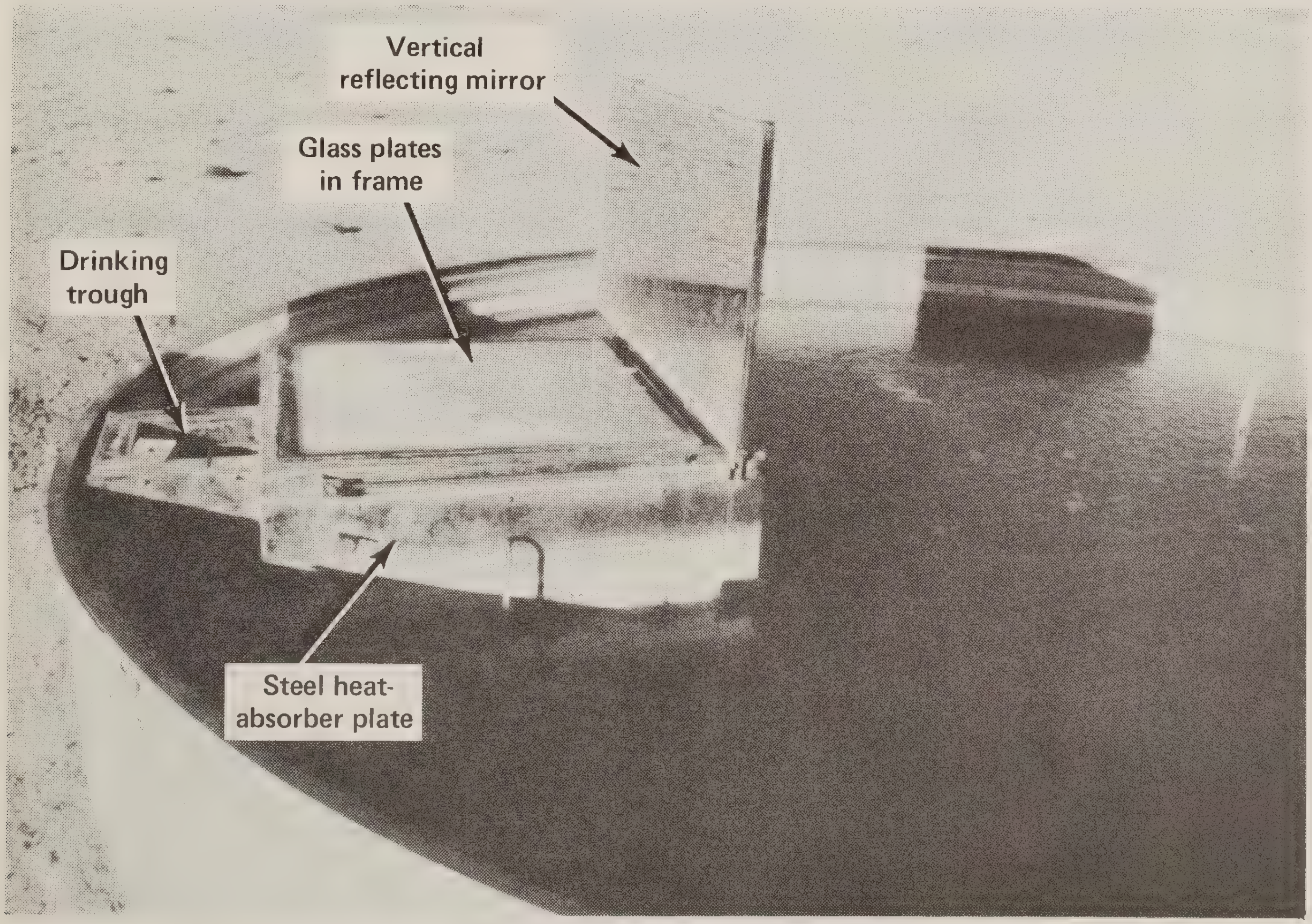

Figure 10. Solar-heated, water-immersed, insulated tank in a standard stock tank.

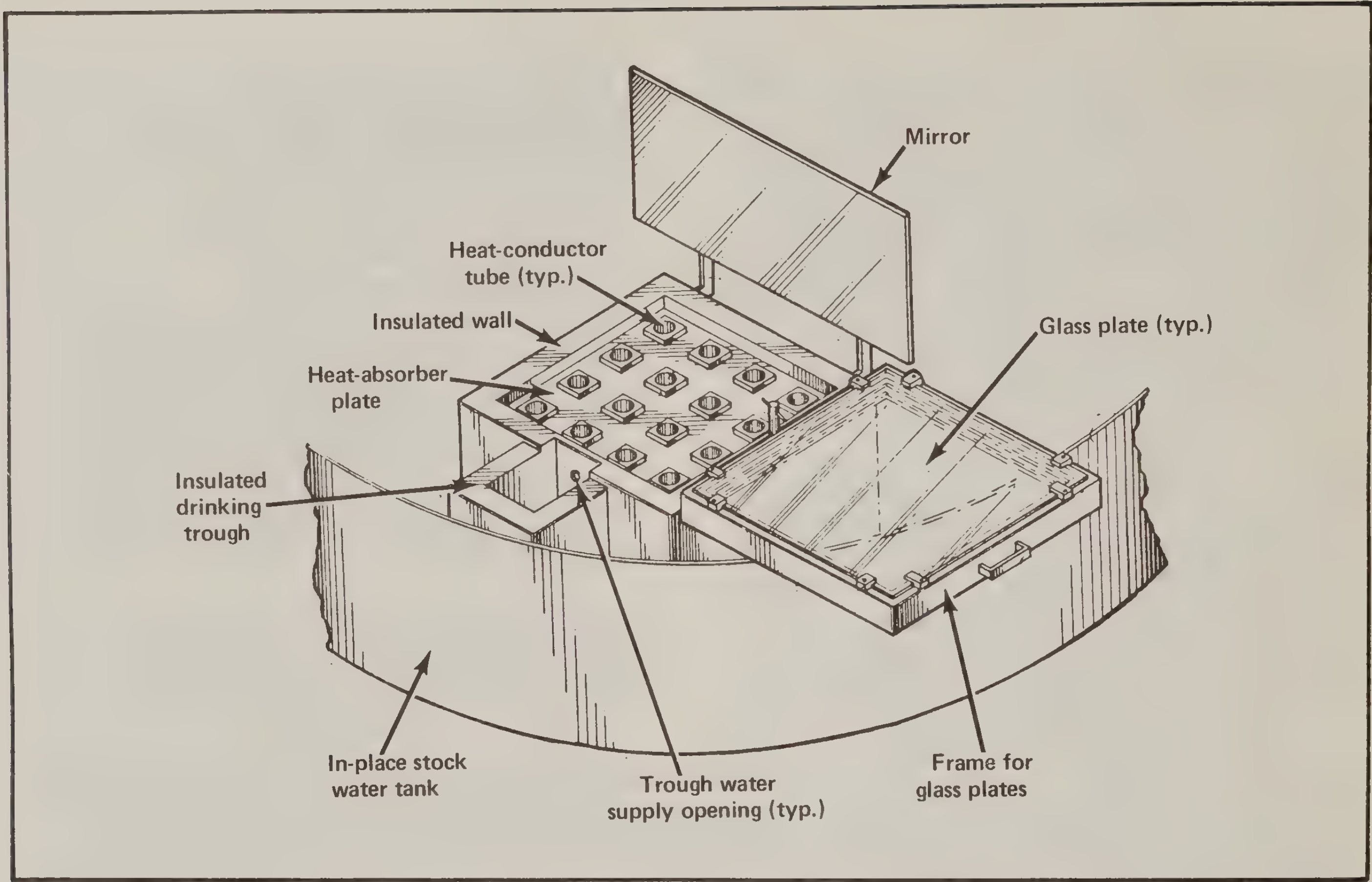

Figure 11. Major components of solar-heated, water-immersed, insulated tank.

immersed tank. Openings in the insulated walls of the water-immersed tank permit the water level within the two tanks to equalize, preventing overflow from the solar-heated, water-immersed tank.

The insulated tank (fig. 11) has a transparent covering, which consists of glass plates mounted in a frame. Below this covering is a steel plate that is above the water level in the solar-heated, water-immersed tank. Sunlight passes through the glass plates to heat both the steel plate and the air trapped between the glass and steel plate. Descending from the steel heat-absorber plate are copper tubes that conduct the heat energy, which builds up in the steel plate, to the water within the water-immersed, insulated tank.

Heating of the trapped air above the metal plate produces a greenhouse (or, if you prefer, hothouse) effect that enhances the heating of the steel heat-absorber plate. Heating of the plate is also aided by a mirror, mounted vertically on the back wall of the solar-heated, water-immersed tank. The mirror directs additional sunlight through the transparent covering to the metal plate. An insulated drinking trough, mounted on the front outside of the tank wall receives water through openings that allow solar-heated water to circulate. A convection current is created that continuously supplies drinking water for the livestock.

Mr. Sitter reports that the solar-heated, water-immersed, insulated tank can be mass produced for approximately $1,000 each.

The Solar Energy Research Institute suggested a much simpler and lower-cost water-immersed insulated tank. The solar energy is absorbed directly into the water as well as the tank sides and bottom. The dimensions shown in figure 12 are designed to allow pickup truck transportation; other dimensions are acceptable. The sides would be insulated with waterproof material and the inside of the tank painted black to absorb the sun's rays. A low-cost glazing would cover the top of the tank, and inlet and outlet ports would allow water movement. The water inlet into the stock tank would be into the water-immersed insulated tank. Also, a reflector would be mounted on the back facing south to improve performance and assist in melting snow.

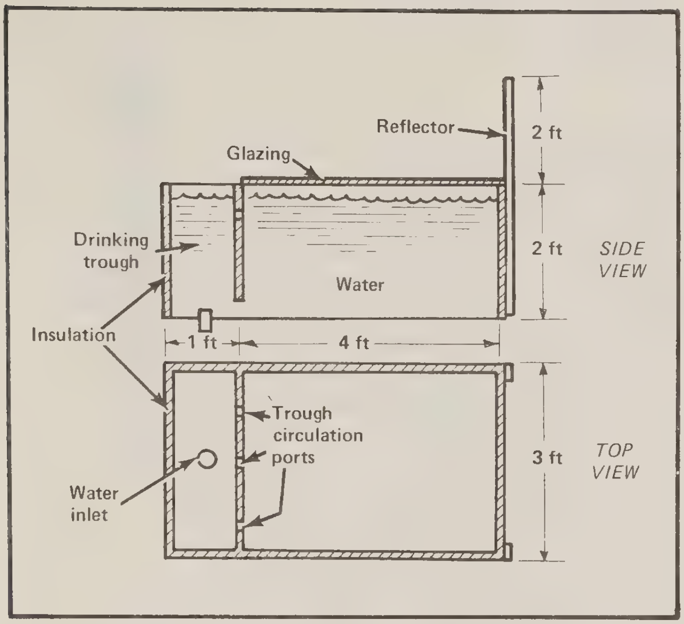

Figure 12. Water-immersed insulated tank suggested by Solar Energy Research Institute.

In-the-Ground Insulated Tank. Randall L. DeGroot of Columbia, Mo., has also designed a solar-heated stock tank that utilizes the greenhouse effect. It is an insulated tank, sunk into the ground, having a transparent fiberglass cover facing south at a 45-degree tilt (fig. 13). Livestock gain access to the solar-heated water in the buried tank through two hinged spring doors in an insulated wall opposite the transparent wall. Solar radiation is absorbed through the transparent cover and the heat is stored in the water. As with the water-immersed tank, insulation helps prevent heat loss.

The swinging doors may be a problem to livestock drinking by getting a head caught. By replacing them with a curtain, this problem may be reduced or eliminated. However, care must be taken to ensure that the curtain does not become wet, since it could then freeze and close the opening.

Using a mathematical model, Mr. DeGroot has estimated that the water in the tank should remain liquid even through severe winter conditions at a latitude of 40° N. He also points out that one can insulate the sides of an existing on-the-ground stock water tank and place a transparent cover over it. This cover would have to have doors,

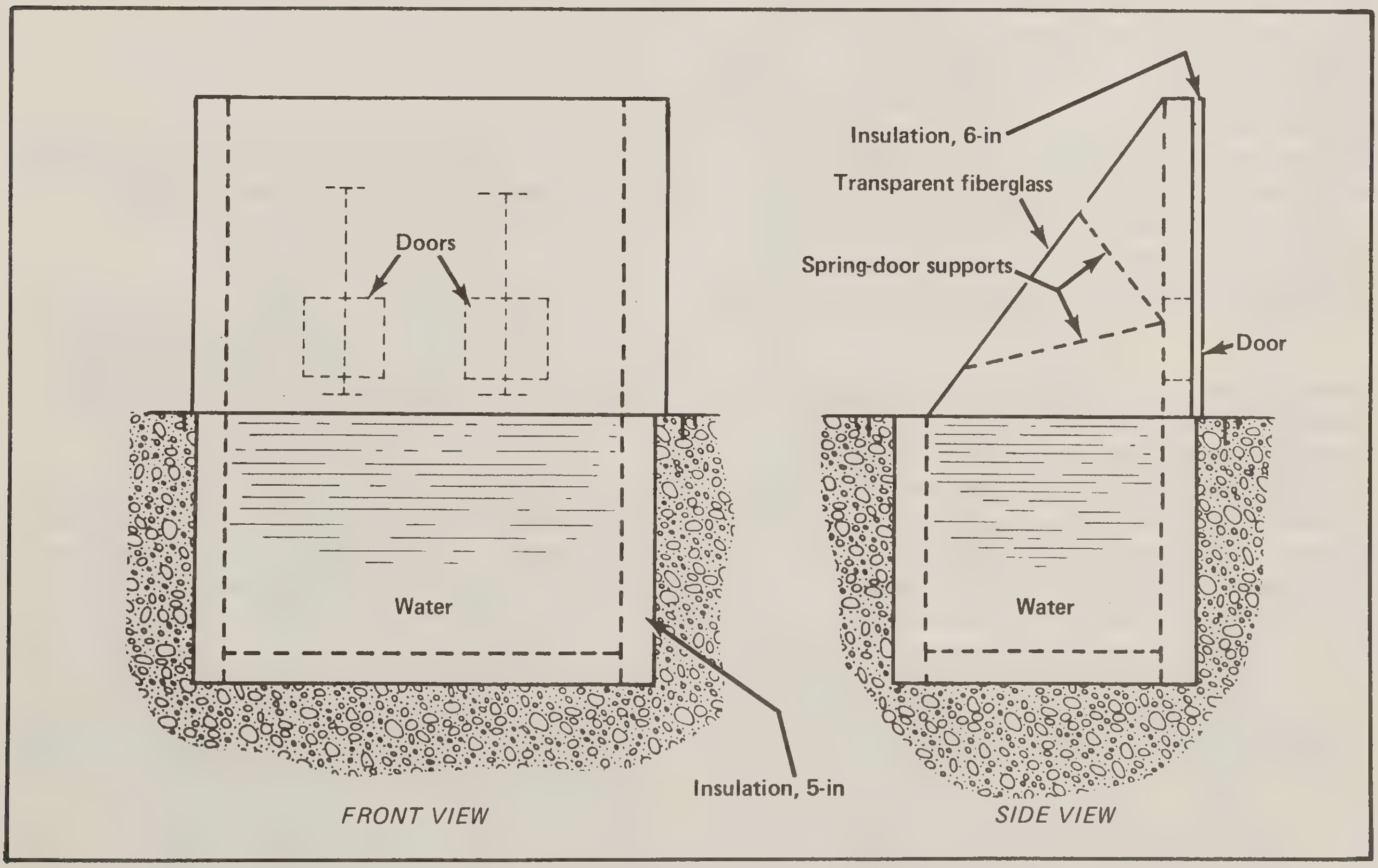

Figure 13. Solar-heated, in-the-ground stock tank schematic.

curtains, or openings to provide the livestock with access to the solar-heated water.

Solar Collectors

Collectors transfer incoming solar radiation to a medium (typically water or air) circulating in tubes. Focusing, or concentrating, collectors use some type of lens or reflector that focuses the solar radiation onto a pipe or boiler containing a heat storage/transfer medium. Since these solar concentrators must receive direct sunlight, a tracking mechanism is used to point the lens or reflector directly at the sun throughout daylight hours. Frensel lenses and a disk or cylindrical parabolic mirrors are typically used to focus the sunlight and can produce temperatures up to 575° F (300° C). Tracking mechanisms are necessary for the operation of systems using lenses, dishes, or parabolic reflectors. These mechanisms are expensive and require maintenance, and are not recommended for freeze-preventative systems.

Flat-plate collectors, which produce lower temperatures, consist of pipes or tubes that are fastened to an absorber plate, which is placed in casing. Copper is the best material for the absorber plate and tubing since it conducts heat better than most metals and is corrosion resistant. Water, an antifreeze solution, or air is usually the medium circulated in the tubes. Both direct and diffused sunlight heats the absorber plate and the tubes fastened to it, in turn heating the fluid in the tubes. The box or casing, which is insulated behind the absorber plate to reduce heat loss, usually has a top of one or two sheets of glazing to allow sunlight in and to retain heat in a manner similar to the greenhouse effect. Flat-plate collectors cost \$11 to \$19/sq ft (\$112 to \$194/m^2).

Passive flat-plate collector systems use a thermosiphon to move the circulating heat-transfer fluid. These systems appear to be impractical for stock water tank freeze prevention, since the flat-plate collector has to be located at a lower elevation than the heat exchanger which would be located in the stock tank. Providing these collectors with adequate exposure, protection, and a sufficient elevation difference may be difficult at typical stock tank sites. Thermosiphon systems have a very small circulating force, and larger-than-normal piping has to be used to reduce pressure loss due to pipe friction. The pipes in these passive systems have to be sloped to avoid formation of air pockets that could retard or stop circulation.

Further, the required heat-transfer fluid, an antifreeze solution, expands as it is heated. This means that an expansion tank and an air purger have to be added to the system. However, this system may be practical if a location where it can be used is found and the cost of flat plate collectors is not excessive. Often, water sources are from a well placed near the bottom of a valley, but not quite in the lowest portion where flooding might silt up the well.

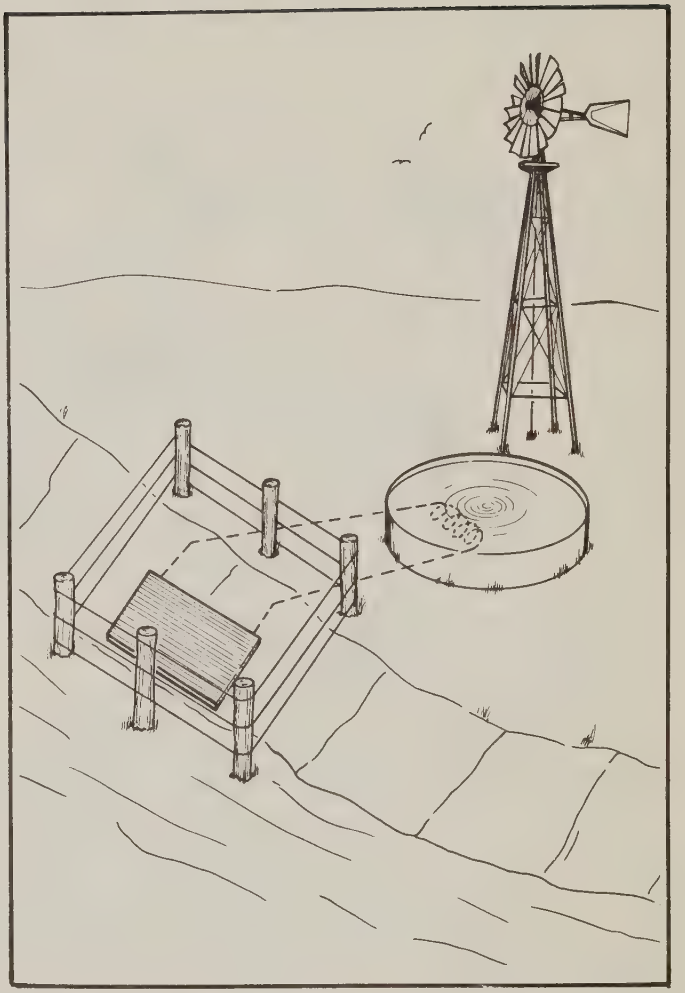

Figure 14. Thermosiphon flat-plate collector mounted on side of arroyo.

If there were an arroyo running east and west, with a well and stock tank on the north bank (in northern latitudes) close to the arroyo, this would present an optimum location for the thermosiphon system. The panel could be placed or suspended over the edge of the arroyo and pipes run to a heat exchanger in the tank. The top of the panel should, if possible, be 2-ft below the bottom of the bank to prevent reverse thermosiphoning at night. If the vertical distance is less than a foot, a very sensitive check valve or flapper valve should be provided to prevent reverse flow. This is a passive alternative to the "solar-heated stock tank."

Flat-Plate Collector System with Photovoltaics

A proposed water tank freeze-preventative device (fig.

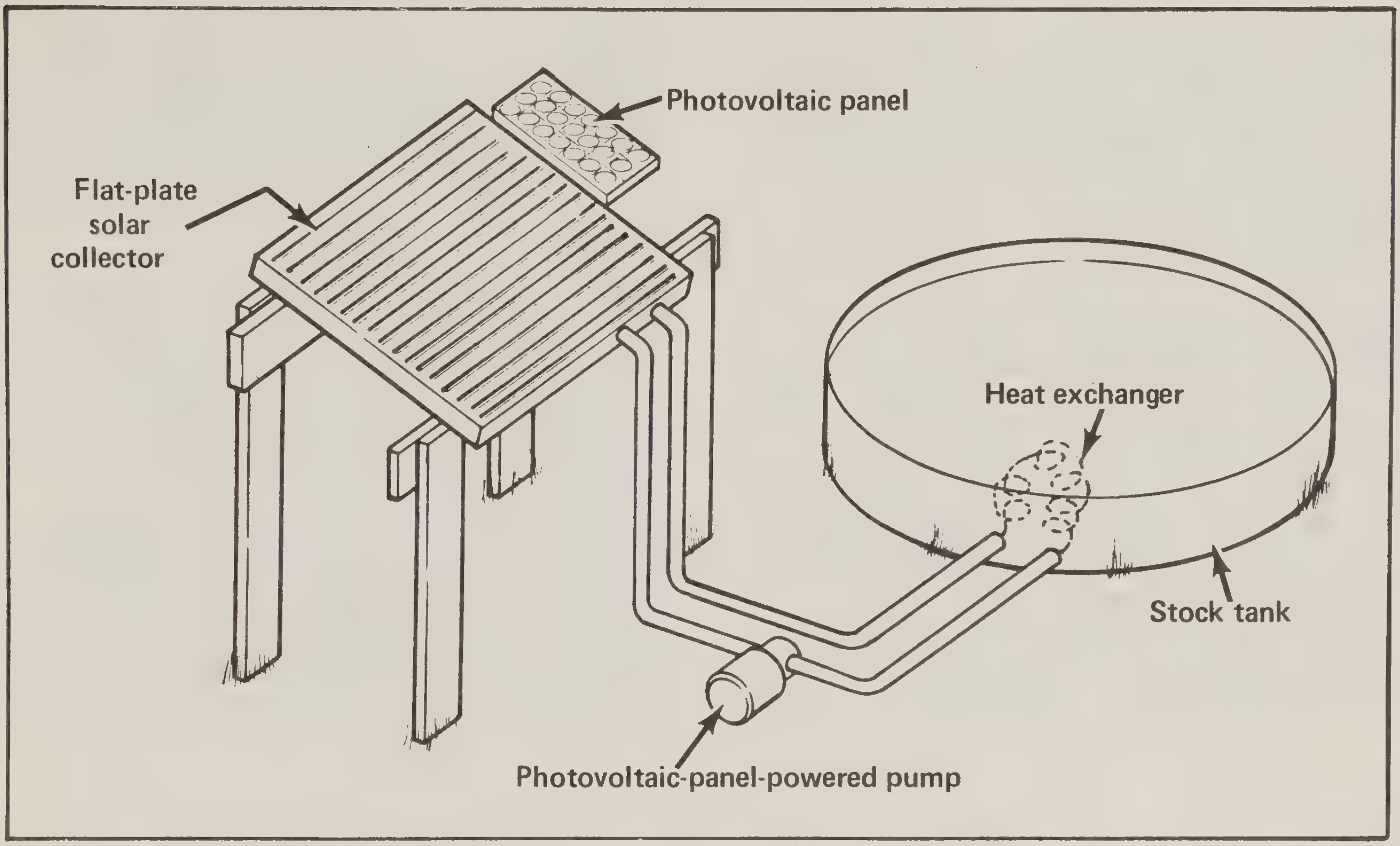

Figure 15. Active flat-plate collector freeze-prevention system.

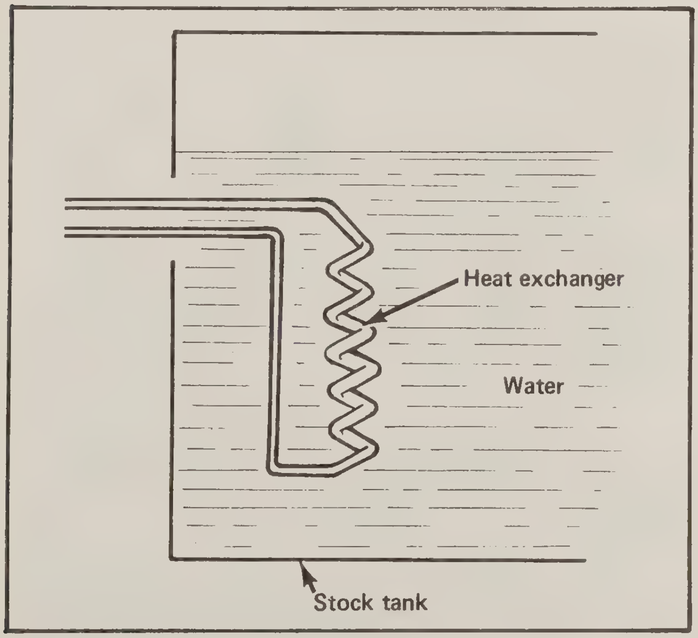

Figure 16. Schematic of heat exchanger within stock tank.

15) uses a flat-plate collector with a photovoltaic-powered electric pump to circulate the heat-transfer medium—an anti-freeze solution such as nontoxic propylene glycol. Since the electric pump (20 to 80 watts) provides the circulation power, collector elevation is not critical—provided the flat-plate collector is placed as near the heat exchanger, located in the stock tank, as possible. Essentially, the device consists of the small pump and its photovoltaic panel, plus a flat-plate collector connected by insulated piping to a heat exhcnager (fig. 16) and an expansion tank. This heat exchanger is installed within the standard stock tank.

The flat-plate collector and photovoltaic panel should face straight south or a little southeast at the appropriate tilt angle for the site to receive maximum morning sunlight. When the sun first strikes the site, the pump begins

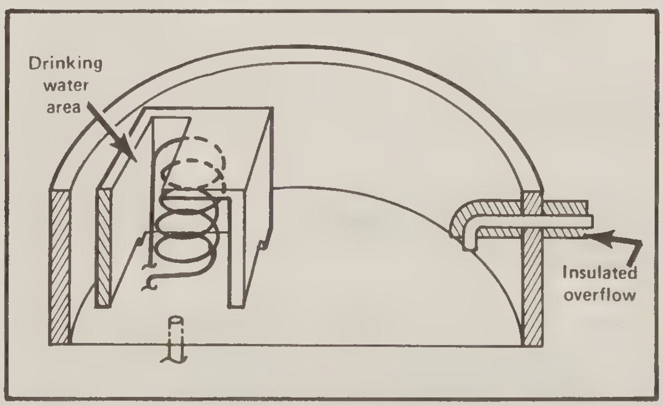

Figure 17. Cross-section of water-immersed insulated box with heat exchanger and water inlet into insulated box.

circulation and the collector begins heating the antifreeze solution. The circulating, heated solution flows through a heat exchanger within the stock tank. The heat exchanger within the stock tank could also be placed in a water-immersed insulated box or tank so only a small amount of water would be warmed first making drinking water available to stock (fig. 17).

Solar Pond with Electric Pump

A solar pond is made by filling a pond that is 9- to 12-ft (3- to 4-m) deep as follows: The bottom 4 to 6 ft (1.2 to 2 m) is filled with a solution of 17 to 26 percent salt concentration (an almost saturated solution). The next 3 to 4 ft (0.9 to 1.2 m) is filled with a salt solution increasing in salinity with increasing depth. Then a surface layer of fresh water ¾ to 1½ ft (0.2 to 0.5 m) is added. This provides a nearly linear density gradient between a surface layer of nearly fresh water and the concentrated brine in the bottom. Over a period of time, the bottom of the pond will become hot due to the absorption of solar energy and the suppression of natural convection by the density gradients in the salt solution. There is sufficient heat absorbed so that the pond can supply thermal energy to a load. Suppression of wave action is essential to preserve the gradient layer. Periodic flushing of the surface and replenishment of concentrated brine in the bottom are essential maintenance functions.

Solar ponds are subject to many economies of scale, with the result that larger ponds are significantly more cost-effective than small ones. This is due, in part, to the fixed costs associated with maintenance equipment and heat extraction equipment requirements which do not vary linearly with pond size. In addition, a small solar pond has a large ratio of perimter-to-surface area, resulting in less efficient performance due to a higher percentage of losses out the sides than would be experienced in a larger pond. A pond of the size required to prevent stock tank freezing would probably not be cost-effective, particularly with the added cost of photovoltaics to run a pump with a heat exhanger in a stock tank.

CONCLUSIONS

Our survey of available equipment for, and approaches to, preventing livestock water from freezing (see table 1) shows that a rancher or farmer should be able to avoid manual ice chopping at remote livestock watering sites by using one of the methods, marketed or proposed, discussed in this Project Record. However, it may not be practical nor economical to do so. Specifically:

1. Use of insulated covers and applying insulation to the sides of stock tanks should be considered for ice-free stock water tanks.

2. The propane bubbler seems the most simple and cost-effective freeze-prevention technique in climates that are not extreme.

3. Photovoltaic-powered, water-circulation pumps appear to be practical and, because of their low cost, should be further investigated.

4. Mass-insulated tanks are probably one of the simplest and most certain of the approaches presented for preventing freezing in livestock watering tanks.

5. Heat pipes are an alternative to the propane bubbler that do not require a nonrenewable energy source. In colder climates than the New Mexico area, the rate of heat transfer may not be sufficient to prevent freezing. However, the technique shows promise, appears economical, and is considered worthy of further evaluation.

6. Photovoltaic cells to power an electric coil heater for freeze prevention in livestock stock tanks is impractical because of the high cost of the photovoltaic cells. However, if commercial electric power is available, the electric coil heater for freeze prevention in stock tanks is very practical.

7. Solar-heated (greenhouse effect), water-immersed, insulated tanks within a stock tank are considered excellent.

8. In-the-ground insulated tanks with access door may be impractical because of the swinging doors; however, if the design were modified with curtains, this problem may be reduced or eliminated.

9. Thermosiphon with a flat-plate collector system appears to be impractical unless just the right location is available.

10. The flat-plate collector systems with photovoltaics-powered pump approach is good although possibly too expensive for consideration at the present time—since the cost of photovoltaics is approximately $10 per peak watt.

11. A small solar pond solar collector, constructed for preventing a stock tank from freezing, would probably not be cost-effective—particularly when considering the high cost of photovoltaics needed to power a pump to move the heat transfer fluid from the pond to the heat exchanger in the stock tank. Maintenance requirements of the solar pond would also be a problem.

RECOMMENDATIONS

Only the following is proposed for Forest Service equipment development in the area of preventing livestock water and livestock water tanks from freezing: An investigation of photovoltaic-powered, water-circulation pumps and the Solar Energy Research Institute water-immersed insulated box. Also, on an opportunity basis, the market search should continue and any new information uncovered should be presented in future VREW annual reports.

If additional equipment development is determined to be necessary in the area of preventing livestock water and livestock tanks from freezing, an agricultural college in an area of frequent below-freezing temperatures should be placed under contract to conduct well-controlled experiments with a number of stock tanks having different types of freeze-prevention systems and with sufficient instrumentation to measure the system performances. The systems should be monitored to understand their operation and much data should be collected on flow rates, temperature stratification, heat loss, heat gain from the ground, solar gain, evaporation losses, source water temperature, etc. In this way, systems for preventing livestock water from freezing could be developed, tested, evaluated, and optimized.

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